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UPRM and ERDC Educational and Research Internship Program

USCS and the USDA Soil Classification System

Development of a Mapping Scheme

Rubén A. García-Gaines and Susan Frankenstein

March 2015

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Abstract

The U.S. Department of Agriculture (USDA) soil classification system is relatively simple to apply while the Unified Soil Classification System (USCS) is more complex. As a result, the USDA system, or a similar method, is more commonly used. However, unless taking direct measurements, the USCS classification is needed to determine soil strength. There is no direct relationship between these soil classification systems, and moving from one scheme to another can be tedious and is inexact. Currently, individual researchers, engineers, and soil scientists have their own mapping to move from one system to another, which can lead to confusion when sharing work with others. A consensus method for mapping from one classification scheme to another would avoid this. By analyzing the mappings from six data sets containing thousands of samples, we form such a consensus.

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Preface

This study was conducted for U.S. Army Engineer Research and Development Center (ERDC) under the UPRM and ERDC Educational and Research Internship Program and T42 62784, “Army Terrestrial Environmental Modeling and Intelligence System (ARTEMIS).” The technical monitor was John Eylander, ERDC Cold Regions Research and Engineering Laboratory (CRREL).

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LTC John Tucker was Acting Commander of ERDC, and Dr. Jeffery P. Holland was the Director.

Acronyms and Abbreviations

AASHTO	American Association of State Highway and Transportation Officials
AFWA	Air Force Weather Agency
ARTEMIS	Army Terrestrial Environmental Modeling and Intelligence System
ASRIS	Australian Soil Resource Information System
CRREL	Cold Regions Research and Engineering Laboratory
ERDC	US Army Engineer Research and Development Center
ESDB	European Soil Database
FAO	Food and Agriculture Organization
FASST	Fast All-Season Soil Strength
GI	Group Index
HWSD	Harmonized World Soil Database
LL	Liquid Limit
NATO	North Atlantic Treaty Organization
NRCS	Natural Resources Conservation Service
NRMM	NATO Reference Mobility Model
NSDB	National Soil DataBase
PL	Plastic Limit
PI	Plasticity Index
RDECOM	Research, Development and Engineering Command
SOTER	Soil and Terrain Database
SSURGO	U.S. Soil Survey Geographic
TARDEC	Army Tank Automotive Research, Development, and Engineering Center
UNESCO	United Nations Educational, Scientific and Cultural Organization
USCS	Unified Soil Classification System
USDA	U.S. Department of Agriculture
WES	Waterways Experiment Station
WISE	World Inventory of Soil Emission Potentials

1 Introduction

Soil characteristics and properties are important to human daily living. A variety of disciplines (geology, agriculture, engineering, etc.) require a systematic categorization of soil, detailing its physical properties. Due to different interests, numerous soil classification systems have been developed worldwide. Many soil scientists share a goal of developing a universally understood and accepted system. Also, it would be advantageous to unite available soils databases and create one global soil database. Many soil databases exist worldwide; most of them use different soil classification systems.

Soil classification systems can be divided into two main groups, one for engineering purposes and another for soil science. For engineering purposes, the following are the most used classification systems (Das 2009):

1. **United States Department of Agriculture (USDA) textural soil classification**
   a. Based on particle size distribution
   b. Commonly used because of its simplicity

2. **American Association of State Highway and Transportation Officials (AASHTO) soil classification**
   a. Based on particle size distribution and soil plasticity
   b. Used mostly by state and county highway departments

3. **Unified Soil Classification System (USCS)**
   a. Based on particle size distribution, liquid limit, soil plasticity, and organic matter concentrations
   b. Widely used by geotechnical engineers

For soil-science purposes, a variety of classification systems have been created for diverse uses. Most of them follow one of the following approaches:

1. **Natural system** (Muir 1969)
   a. Based on soil morphology, behavior, or genesis

b. Examples of classification systems that follow this approach are the French Soil Reference System, USDA soil taxonomy, and the World Reference Base for Soil Resources

2. **Technical system**
   a. Organized and classified into groups for specific applied purposes (Cline 1949)
   b. Relies on the most current practices and an understanding of the intended use of soil or the present land-use regulations (Buol et al. 2011)

3. **Numerical system** (Buol et al. 2011)
   a. Based on statistical analysis (by similitudes)

4. **Vernacular system** (Tabor 2001)
   a. Based on names that describe characteristics, such as physical appearance (e.g., color, texture, landscape position), performance (e.g., production capability, flooding), and accompanying vegetation

However, as we are interested in engineering-related work, we will be focusing mostly on USCS and the USDA and AASHTO soil classification systems.

The USDA soil classification system is relatively simple to apply while USCS and the AASHTO classification system are more complex. There is no direct relationship between these soil classification systems, and moving from one system to another can be tedious and inexact. This presents an obstacle for a person who needs to work with a specific soil classification system but who has soil data that uses another classification system.

A consensus method to map from one classification scheme to another would create the opportunity to use data from diverse databases. Currently, individual researchers, engineers, and soil scientists have their own mapping for moving from one system to another, which can lead to confusion when sharing work.

As a result of trying to develop soil databases for mobility and sensor performance analysis in remote locations, we became interested in comparing

USCS and the USDA system. Except for direct measurement, currently the only other way to determine soil strength uses the USCS classification and the soil water content. Most available databases classify soils using the USDA system while only a few use the USCS method. We hope that our findings can aid those who need to use the USCS approach when the only available soil data is classified using the USDA system.

Many soil databases exist worldwide, containing thousands of soil samples and including information such as water capacity, soil reaction, electrical conductivity, textural class, PH, salinity, clay fraction, sand fraction, etc. The following are some of the best-known soil databases.

1. **SSURGO** (U.S. Soil Survey Geographic): This contains information about soil collected by the National Cooperative Soil Survey. Information is available for most areas of the United States and the territories, commonwealths, and island nations that the USDA-NRCS (United States Department of Agriculture–Natural Resources Conservation Service) serves and was gathered by walking over the land and observing the soil. Lab analysis was performed on many of the samples (http://www.nrcs.usda.gov/wps/portal/nrcs/main/soils/survey/geo/).

2. **NSDB** (National Soil DataBase): This contains soil, landscape, and climatic data for Canada and serves as the national archive for land resources information. It was collected by federal and provincial field surveys or created by land analysis projects (http://sis.agr.gc.ca/cansis/nsdb/index.html).

3. **ASRIS** (Australian Soil Resource Information System): This contains soil and land resource information from Australia. It was developed for a broad range of users, including natural resources managers, educational institutions, planners, researchers, and community groups (http://www.asris.csiro.au).

4. **HWSD** (Harmonized World Soil Database): This combines existing regional and national updates of soil information worldwide—SOTER (Soil and Terrain Database), ESDB (European Soil Database), Soil Map of China, WISE (World Inventory of Soil Emission Potentials)—with information contained within the FAO-UNESCO (Food and Agriculture Organization–United Nations Educational, Scientific and Cultural Organization) Soil

Map of the World. It has over 16,000 different soil-mapping units (http://www.iiasa.ac.at/web/home/research/modelsData/HWSD/HWSD.en.html).

For this analysis we decided to use the SSURGO database because it was the only database from the above list that classifies soils using both USCS and the USDA system. We analyzed the SSURGO data to determine the frequency distribution of a given USDA classification in the USCS schema. We then compared these findings with other sources to see if a consensus exists. Finally, we recommend a mapping for moving from one system to the other.

Specifically, the objectives of this project were to

1. gather and organize data from soils that have been classified in both USCS and the USDA soil textural classification system,
2. determine the frequency of USDA classed soils occurring in the USCS categories, and
3. develop a mapping between the two systems.

2 Background

Textural classification of soil is simple as it is based on only particle-size distribution. For engineering purposes, it is often important to also consider parameters that indicate soil strength. Two important properties used for engineering-related problems are plastic limit and liquid limit. The liquid limit (LL) is defined as the moisture content at which soil begins to behave as a liquid material and begins to flow. The plastic limit (PL) is defined as the moisture content at which soil begins to behave as a plastic material. With these two limits, the plasticity index (PI) can be calculated. Plasticity index is the difference between the liquid limit and plastic limit of a soil. The plasticity index is used to classify the soil and to help interpret soil characteristics properly. Two classification systems used by engineers in the United States that use these extra properties in categorizing soil are the American Association of State Highway and Transportation Officials (AASHTO) and the Unified Soil Classification System (USCS). In this section, we provide more information on the USDA, USCS, and AASHTO methods.

2.1 Soil classification for engineering purposes

2.1.1 USDA textural soil classification

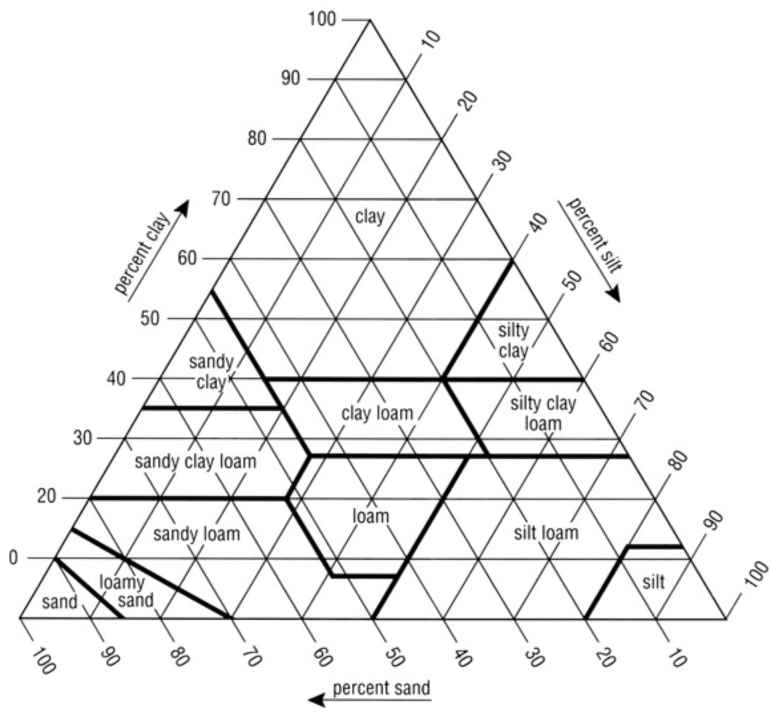
Most of the soil classification systems developed for engineering purposes are based on particle size distribution and soil plasticity. However, one of the most widely used soil classification systems, the USDA textural classification, which the USDA adopted in 1938 (USDA 1987), is based solely on grain size distribution. It is an adaptation of a late 19th century Russian system that permitted the study of soils with the same agricultural characteristics (Curtis 2005). This demonstrates the fact that many textural classification systems were developed to meet specifics needs. In agriculture, textural classification is used to determine crop suitability and to approximate the soil’s response to environmental and management conditions, such as drought or calcium requirements. In water resources engineering, it can be used to determine how much water will infiltrate through a given soil. Because of its relative simplicity compared with other classification systems (USCS, AASHTO, etc.), the USDA method is widely used around the world.

The following are the primary classifications:

- Sand—particle sizes from 2.0 to 0.05 mm in diameter
- Silt—particles sizes from 0.05 to 0.002 mm in diameter
- Clay—particles smaller than 0.002 mm in diameter

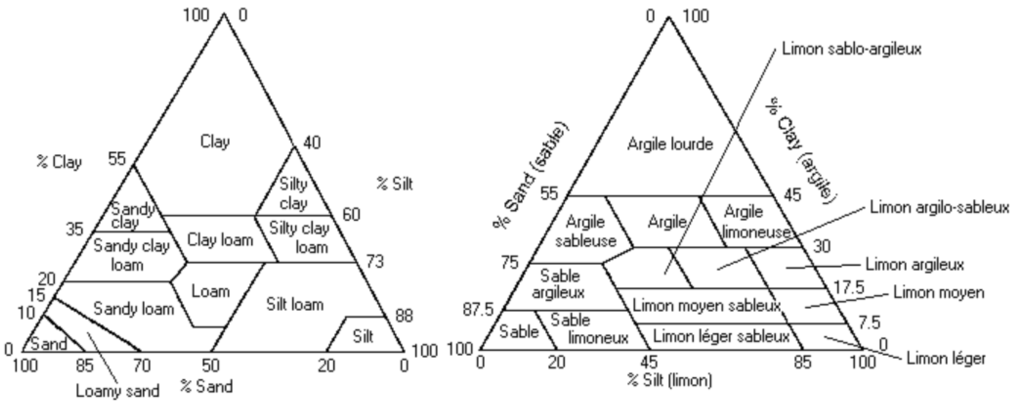
This is further refined for a total of 12 classes. The classes are often displayed on what is known as the USDA triangle, shown in Figure 1.

Figure 1. USDA soil textural triangle (Soil Survey Division Staff 1993).



Textural classification systems similar to the USDA have been developed by other countries, but they are not commonly used outside of their country of origin. Differences in the systems include particle size degradation (in England and Denmark, silt particle size ranges from 0.002 to 0.063 mm); number of total classes (England, Denmark, and Australia have 11 classes); and how the classes are defined in terms of percent sand, silt, and clay. Figure 2 shows the USDA and French textural classification triangles for comparison.

Figure 2. Texture classification triangles (Tabor 2001). The left is from the USDA system, and the right is from the French system.



In all textural classification systems, further refinements are used to distinguish between different sands and gravels. For example, in the USDA system, sand has five subcategories depending on particles diameters as shown in Table 1.

Table 1. USDA soil-separates classifications (Soil Survey Division Staff 1993).

Name of Soil Separate	Diameter Limits (mm)
Very fine sand	0.05–0.10
Fine sand	0.10–0.25
Medium sand	0.25–0.50
Coarse sand	0.50–1.00
Very coarse sand	1.00–2.00

It is important to note that the USDA textural triangle method does not take into consideration rock fragments or organic soils. These kinds of soils require other approaches (Soil Survey Division Staff 1993).

2.1.1.1 Organic Soils

A soil is considered as *organic* if soil layers “are not saturated with water for more than a few days and have 20 percent or more organic carbon. Layers that are saturated for longer periods, or were saturated before being drained, are organic if they have 12 percent or more organic carbon and no clay, 18 percent or more organic carbon and 60 percent or more clay, or a proportional amount of organic carbon, between 12 and 18 percent, if the clay content is between 0 and 60 percent” (Soil Survey Division Staff 1993).

It is named *muck* if it is a "well-decomposed, organic soil material," *peat* (USCS symbol Pt) if it is an "undecomposed, organic material in which the original fibers constitute almost all of the material," and *mucky peat* if it is an "intermediate between muck and peat" (Soil Survey Division Staff 1993).

2.1.1.2 Rock Fragments

As stated in the *Soil Survey Manual* (Soil Survey Division Staff 1993),

> Rock fragments are unattached pieces of rock 2 mm in diameter or larger that are *strongly cemented* or more resistant to rupture. Rock fragments include all sizes that have horizontal dimensions less than the size of a pedon.
>
> Rock fragments are described by size, shape, and, for some, the kind of rock. The classes are *pebbles*, *cobbles*, *channers*, *flagstones*, *stones*, and *boulders*. If a size or range of sizes predominates, the class is modified, as for example: "fine pebbles," "cobbles 100 to 150 mm in diameter," "channers 25 to 50 mm in length."
>
> Gravel is a collection of pebbles that have diameters ranging from 2 to 75 mm. The term is applied to the collection of pebbles in a soil layer with no implication of geological formalization. The terms "pebble" and "cobble" are usually restricted to rounded or subrounded fragments; however, they can be used to describe angular fragments if they are not flat. Words like chert, limestone, and shale refer to a kind of rock, not a piece of rock. The composition of the fragments can be given: "chert pebbles," "limestone channers." The upper size of gravel is 3 inches (75 mm). This coincides with the upper limit used by many engineers for grain-size distribution computations. The 5-mm and 20-mm divisions for the separation of fine, medium, and coarse gravel coincide with the sizes of open-

> ings in the "number 4" screen (4.76 mm) and the "3/4 inch" screen (19.05 mm) used in engineering.
>
> The 75 mm (3 inch) limit separates gravel from cobbles. The 250-mm (10-inch) limit separates cobbles from stones, and the 600-mm (24-inch) limit separates stones from boulders. The 150-mm (channers) and 380 mm (flagstones) limits for thin, flat fragments follow conventions used for many years to provide class limits for plate-shaped and crudely spherical rock fragments that have about the same soil use implications as the 250-mm limit for spherical shapes.

Rock fragments (pebbles, cobbles, stones, etc.) are considered during the classification of a soil. Depending on the size, shape, and percentages of volume of fragments, special adjectives are used to modify the textural term (Soil Survey Division Staff 1993). Table 2 summarizes the specifications and their corresponding adjective.

Table 2. Terms for rock fragments (Soil Survey Division Staff 1993).

Shape and Size[1]	Noun	Adjective
Spherical, cubelike, or equiaxial		
2–75 mm diameter	Pebbles	Gravelly
2–5 mm diameter	Fine	Fine gravelly
5–20 mm diameter	Medium	Medium gravelly
20–75 mm diameter	Coarse	Coarse gravelly
75–250 mm diameter	Cobbles	Cobbly
250–600 mm diameter	Stones	Stony
>600 mm diameter	Boulders	Bouldery
Flat		
2–150 mm long	Channers	Channery
150–380 mm long	Flagstones	Flaggy
380–600 mm long	Stones	Stony
>600 mm long	Boulders	Bouldery

[1] The roundness of the fragments may be indicated as angular (strongly developed faces with sharp edges), irregular (prominent flat faces with incipient rounding or corners), subrounded (detectable flat faces with well-rounded corners), and rounded (flat faces absent or nearly absent with all corners).

As stated by Soil Survey Division Staff (1993), if less than 15% of the volume is rock fragments, no adjective will be used for the texture term. If the percentage is between 15% and 35%, the adjectival term of the dominant kind of rock fragment is used to modify the texture term. From 35% to 60%, the adjectival term of the dominant kind of rock fragment is used with the word "very" to modify the texture term. If more than 60% of the volume is rock fragments and enough fine earth is present to determine the textural class, the adjectival term of the dominant kind of rock fragment is used with the word "extremely" to modify the texture term. If there is too little fine earth to determine the textural class, the term "gravel," "cobbles," "stones," or "boulders" is used as appropriate.

2.1.2 American Association of State Highway and Transportation Officials (AASHTO) soil classification

The ASSHTO system is used mostly by state and county highway departments. As explained by Das (2009) in *Principles of Geotechnical Engineering*,

> The AASHTO system was developed in 1929 as the Public Road Administration classification system. It has undergone several revisions, with the present version proposed by the Committee on Classification of Materials for Subgrades and Granular Type Roads of the Highway Research Board in 1945 (ASTM designation D-3282; AASHTO method M145). . . .
>
> According to this system, soil is classified into seven major groups: A-1 through A-7. Soils classified under categories A-1, A-2, and A-3 are granular materials of which 35% or less of the particles pass through the No. 200 sieve. Soils of which more than 35% of the particles pass through the No. 200 sieve are classified using categories A-4, A-5, A-6, and A-7. These soils are mostly silt and clay-type materials. This classification system is based on the following criteria:
>
> 1. *Grain size*

   a. *Gravel*: fraction passing the 75-mm sieve and retained on the No. 10 (2-mm) U.S. sieve
   b. *Sand*: fraction passing the No. 10 (2-mm) U.S. sieve and retained on the No. 200 (0.075-mm) U.S. sieve
   c. *Silt and clay*: fraction passing the No. 200 U.S. sieve
2. *Plasticity*: The term *silty* is applied when the fine fractions of the soil have a plasticity index of 10 or less. The term *clayey* is applied when the fine fractions have a plasticity index of 11 or more.
3. If cobbles and *boulders* (size larger than 75 mm) are encountered, they are excluded from the portion of the soil sample from which classification is made. However, the percentage of such material is recorded.

There are subcategories for A-1, A-2, and A-7. A-1 and A-2 subcategories depend on soil's granulometry (particle size distribution). A-7 subcategories depend on plasticity index and liquid limit. Table 3 summarizes (Das 2009).

According to Das (2009),

> To evaluate the quality of a soil as a highway subgrade material [in the AASHTO classification system], one must also incorporate a number called the group index (*GI*) with the groups and subgroups of the soil. This index is written in parentheses after the group or subgroup designation. The group index is given by the equation
>
> $$GI = \left(F_{200} - 35\right)\left[0.2 + 0.005\left(LL - 40\right)\right] + 0.01\left(F_{200} - 15\right)\left(PI - 10\right)$$
> $$GI = \text{round}\left(\max\left(0, GI\right)\right) \tag{1}$$
>
> where F_{200} = percentage passing the No. 200 sieve
> LL = liquid limit
> PI = the plasticity index . . .

Table 3. Classification of highway subgrade materials (Das 2009).

General classification	Granular materials (35% or less of total sample passing No. 200)						
	A-1			A-2			
Group classification	A-1-a	A-1-b	A-3	A-2-4	A-2-5	A-2-6	A-2-7
Sieve analysis (percentage passing)							
No. 10	50 max.						
No. 40	30 max.	50 max.	51 min.				
No. 200	15 max.	25 max.	10 max.	35 max.	35 max.	35 max.	35 max.
Characteristics of fraction passing No. 40							
Liquid limit				40 max.	41 min.	40 max.	41 min.
Plasticity index	6 max.		NP	10 max.	10 max.	11 min.	11 min.
Usual types of significant constituent materials	Stone fragments, gravel, and sand		Fine sand	Silty or clayey gravel and sand			
General subgrade rating	Excellent to good						

General classification	Silt-clay materials (more than 35% of total sample passing No. 200)			
Group classification	A-4	A-5	A-6	A-7 A-7-5[a] A-7-6[b]
Sieve analysis (percentage passing)				
No. 10				
No. 40				
No. 200	36 min.	36 min.	36 min.	36 min.
Characteristics of fraction passing No. 40				
Liquid limit	40 max.	41 min.	40 max.	41 min.
Plasticity index	10 max.	10 max.	11 min.	11 min.
Usual types of significant constituent materials	Silty soils		Clayey soils	
General subgrade rating	Fair to poor			

[a]For A-7-5, $PI \leq LL - 30$
[b]For A-7-6, $PI > LL - 30$

For soils belonging to groups A-1-a, A-1-b, A-2-4, A-2-5, and A-3, $GI = 0$. Also, when calculating GI for soils that belong to groups A-2-6 and A-2-7, use only term 2 in equation (1) (Das 2009).

Organic soils have undesirable properties and should be avoided, if possible, for all types of construction (New Mexico Department of Transportation 2012). They are normally classified under the A-7 category. Highly organic soils, such as peat or muck, are not included in this classification.

2.1.3 Unified Soil Classification System (USCS)

The most used soil classification system among engineers is USCS. It was originally developed by Casagrande (1948) for use in the airfield construction works undertaken by the Army Corps of Engineers during World War II. In cooperation with the U.S. Bureau of Reclamation, the Waterways Experiment Station (WES) revised this system in 1952 to make it applica-

ble to dams, foundations, and other constructions (WES 1960). An important difference is that, unlike the USDA and AASHTO systems, USCS incorporates organic soils as well as gravels. As explained by Das (2009),

> This system classifies soils into two broad categories:
>
> 1. Coarse-grained soils that are gravelly and sandy in nature with less than 50% passing through the No. 200 sieve. The group symbol start with a prefix of G or S. G stands for gravel or gravelly soil, and S for sand or sandy soil.
> 2. Fine-grained soils are with 50% or more passing through the No. 200 sieve. The group symbols start with prefixes of M, which stands for inorganic silt, C for inorganic clay, or O for organic silts and clays. The symbol Pt is used for peat, muck, or other highly organic soils.
>
> This system also uses other symbols as:
>
> - W—well graded
> - P—poorly graded
> - L—low plasticity (liquid limit less than 50)
> - H—high plasticity (liquid limit more than 50)
>
> For proper classification according to this system, some or all of the following information must be known:
>
> 1. Percent of gravel—that is, the fraction passing the 76.2-mm sieve and retained on the No. 4 sieve (4.75-mm opening)
> 2. Percent of sand—that is, the fraction passing the No. 4 sieve (4.75-mm opening) and retained on the No. 200 sieve (0.075-mm opening)
> 3. Percent of silt and clay—that is, the fraction finer than the No. 200 sieve (0.075-mm opening)
> 4. Uniformity coefficient (C_u) and the coefficient of gradation (C_c)

5. Liquid limit and plasticity index of the portion of soil passing the No. 40 sieve

The group symbols for coarse-grained gravelly soils are GW, GP, GC, GC-GM, GW-GM, GW-GC, GP-GM, and GP-GC. Similarly, the group symbols for fine-grained soils are CL, ML, OL, CH, MH, OH, CL-ML, and Pt.

Soils will be classified as organic clay if it is clay with sufficient organic content to influence the soil properties. For classification, organic clay is a soil that would be classified as clay except that its liquid limit value after oven drying is less than 75 % of its liquid limit value before oven drying.

Soils will be classified organic silt if it is silt with sufficient organic content to influence the soil properties. For classification, organic silt is a soil that would be classified as silt except that its liquid limit value after oven drying is less than 75 % of its liquid limit value before oven drying.

Pt is the classification for highly organic soils. A soil is considered highly organic if it is primarily composed of organic matter, is dark in color, and has an organic odor.

These types of criterions in their present form do not discriminate between soils containing different amounts of organic matter, and no specific carbon levels are required (Huang et al. 2009).

Dual symbols SW-SM, SW-SC, SP-SM, and SP-SC are for sands with 5% to 12% fines. CL-ML and SC-SM are used for fine-grained soils with liquid limits between 12 and 25 and plasticity indexes between 4 and 7. Soils that contain similar fines and coarse-grained fractions can be classified as GM-ML (Das 2009; ASTM International 2006).

Table 4 and Figure 3 (Das 2009) provide a summary of USCS classification parameters.

Table 4. Unified Soil Classification System (Das 2009).

Criteria for assigning group symbols				Group symbol
Coarse-grained soils More than 50% of retained on No. 200 sieve	**Gravels** More than 50% of coarse fraction retained on No. 4 sieve	Clean Gravels Less than 5% fines[a]	$C_u \geq 4$ and $1 \leq C_c \leq 3$[c]	GW
			$C_u < 4$ and/or $1 > C_c > 3$[c]	GP
		Gravels with Fines More than 12% fines[a,d]	*PI* < 4 or plots below "*A*" line (Figure 5.3)	GM
			PI > 7 and plots on or above "*A*" line (Figure 5.3)	GC
	Sands 50% or more of coarse fraction passes No. 4 sieve	Clean Sands Less than 5% fines[b]	$C_u \geq 6$ and $1 \leq C_c \leq 3$[c]	SW
			$C_u < 6$ and/or $1 > C_c > 3$[c]	SP
		Sands with Fines More than 12% fines[b,d]	*PI* < 4 or plots below "*A*" line (Figure 5.3)	SM
			PI > 7 and plots on or above "*A*" line (Figure 5.3)	SC
Fine-grained soils 50% or more passes No. 200 sieve	**Silts and clays** Liquid limit less than 50	Inorganic	*PI* > 7 and plots on or above "*A*" line (Figure 5.3)[e]	CL
			PI < 4 or plots below "*A*" line (Figure 5.3)[e]	ML
		Organic	$\frac{\text{Liquid limit — oven dried}}{\text{Liquid limit — not dried}} < 0.75$; see Figure 5.3; OL zone	OL
	Silts and clays Liquid limit 50 or more	Inorganic	*PI* plots on or above "*A*" line (Figure 5.3)	CH
			PI plots below "*A*" line (Figure 5.3)	MH
		Organic	$\frac{\text{Liquid limit — oven dried}}{\text{Liquid limit — not dried}} < 0.75$; see Figure 5.3; OH zone	OH
Highly Organic Soils	Primarily organic matter, dark in color, and organic odor			Pt

[a] Gravels with 5 to 12% fine require dual symbols: GW-GM, GW-GC, GP-GM, GP-GC.

[b] Sands with 5 to 12% fines require dual symbols: SW-SM, SW-SC, SP-SM, SP-SC.

[c] $C_u = \frac{D_{60}}{D_{10}};\quad C_c = \frac{(D_{30})^2}{D_{60} \times D_{10}}$

[d] If $4 \leq PI \leq 7$ and plots in the hatched area in Figure 5.3, use dual symbol GC-GM or SC-SM.

[e] If $4 \leq PI \leq 7$ and plots in the hatched area in Figure 5.3, use dual symbol CL-ML.

Figure 3. Plasticity chart (Das 2009).

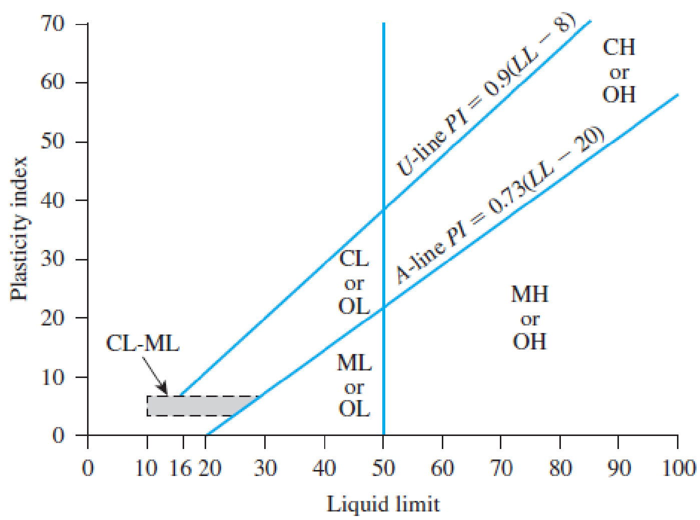


Table 5 presents a comparison of particle size scales between the USDA, USCS, AASHTO, and others soil classification systems.

Table 5. Comparison of particle size scales (Soil Survey Division Staff 1993).

U.S.D.A.	CLAY	SILT		SAND					GRAVEL			COB-BLES	STONES
		fi.	co.	v.fi.	fi.	med.	co.	v.co.	fi.	med.	co.		
	.002		.05					2			76	250mm	

UNIFIED	SILT OR CLAY	SAND			GRAVEL		COBBLES
		fi.	med.	co.	fi.	co.	
	.074			4.76		76mm	

AASHO	CLAY	SILT	SAND		GRAVEL OR STONES			BOULDERS
			fi.	co.	fi.	med.	co.	
	.005	.074		2			76mm	

2.2 Comparison of USCS and the AASHTO system

In *A Review of Engineering Soil Classification Systems,* Liu (1967) compared the AASHTO, USCS, and FAO soil classification systems to identify whether or not these schema properly classify the soils with particular reference to transportation engineering. Tables 6 and 7 summarize findings from Liu (1967), which are also discussed by Das (2009). Table 6 shows the mapping from AASHTO to USCS while Table 7 presents the reverse. This is similar to the approach we want to use to compare USCS and the USDA soil classification system.

Table 6. Comparison of the AASHTO system with USCS (Das 2009).

Soil Group in AASHTO System	Comparable Soil Groups in USCS		
	Most Probable	Possible	Possible but Improbable
A-1-a	GW, GP	SW, SP	GM, SM
A-1-b	SW, SP, GM, SM	GP	—
A-3	SP	—	SW, GP
A-2-4	GM, SM	GC, SC	GW, GP, SW, SP
A-2-5	GM, SM	—	GW, GP, SW, SP
A-2-6	GC, SC	GM, SM	GW, GP, SW, SP
A-2-7	GM, GC, SM, SC	—	GW, GP, SW, SP
A-4	ML, OL	CL, SM, SC	GM, GC
A-5	OH, MH, ML, OL	—	SM, GM
A-6	CL	ML, OL, SC	GC, GM, SM
A-7-5	OH, MH	ML, OL, CH	GM, SM, GC, SC
A-7-6	CH, CL	ML, OL, SC	OH, MH, GC, GM, SM

Table 7. Comparison of USCS with the AASHTO system (Das 2009).

Soil Group in USCS	Comparable Soil Groups in AASHTO System		
	Most Probable	Possible	Possible but Improbable
GW	A-1-a	—	A-2-4, A-2-5, A-2-6, A-2-7
GP	A-1-a	A-1-b	A-3, A-2-4, A-2-5, A-2-6, A-2-7
GM	A-1-b, A-2-4, A-2-5, A-2-7	A-2-6	A-4, A-5, A-6, A-7-5, A-7-6, A-1-a
GC	A-2-6, A-2-7	A-2-4	A-4, A-6, A-7-6, A-7-5
SW	A-1-b	A-1-a	A-3, A-2-4, A-2-5, A-2-6, A-2-7
SP	A-3, A-1-b	A-1-a	A-2-4, A-2-5, A-2-6, A-2-7
SM	A-1-b, A-2-4, A-2-5, A-2-7	A-2-6, A-4	A-5, A-6, A-7-5, A-7-6, A-1-a
SC	A-2-6, A-2-7	A-2-4, A-6, A-4, A-7-6	A-7-5
ML	A-4, A-5	A-6, A-7-5, A-7-6	—
CL	A-6, A-7-6	A-4	—
OL	A-4, A-5	A-6, A-7-5, A-7-6	—
MH	A-7-5, A-5	—	A-7-6
CH	A-7-6	A-7-5	—
OH	A-7-5, A-5	—	A-7-6
Pt	—	—	—

3 Data and Methods

As discussed in the earlier sections, dozens of soil classification systems have been developed around the World to address various needs. Each classification system describes particular soil properties (permeability, strength, color, etc.) and follows its own scheme (particles-size distribution, morphology, etc.). There is no direct relationship between soil classification systems, and moving from one to another can be a difficult task. Because of its relative simplicity (Das 2009), most soil databases classify soils using a textural classification system. Few do the necessary further analysis to classify in another schema (USCS, AASHTO, etc.).

In engineering, the USDA textural classification system is not commonly used because it fails to describe important soil properties (e.g., plasticity). For this reason, engineers prefer USCS. Some mappings have been created between USCS and the USDA classification system, but discrepancies exist between them. Our goal is to create a mapping between USCS and the USDA soil classification system from consensus between different data sources. This mapping will allow for soil data with only USDA classifications to be classified using USCS. As a result, more data will be available for engineering interests.

We used many data sources for this study. These include SSURGO (Soil Survey Staff 2014); Waterways Experiment Station (WES 1961); Wilson, Nuttall, Raimond Engineers (1965); Rollings and Rollings (1996); Ayers et al. (2011); Baylot et al. (2013); and Frankenstein (2014). Each is described in detail below. It is possible that there is overlap between the Rollings and Rollings (1996); Wilson, Nuttall, Raimond Engineers (1965); and WES (1961) data sets, but we were unable to discern this based on the information given.

3.1 U.S. Soil Survey Geographic (SSURGO) data

The USDA-NRCS SSURGO database contains soil information collected over the course of a century and includes data for thousands of soil samples for most areas of the United States and the territories, commonwealths, and island nations served by the USDA-NRCS. For many loca-

tions, soils in SSURGO are classified using both USCS and the USDA soil classification system. After discarding samples that were not classified using both systems, we selected a total of 9258 samples. Data was downloaded to Microsoft Excel and organized into their corresponding classification categories. A total of 2521 samples were classified as having rock fragments (pebbles, cobbles, stones, boulders, etc.). We used this information to map to the USCS gravel soil types. Finally, we determined the frequency of USCS classifications per USDA classification. Table 8 shows the total number of USDA soil types for each USCS category. The two most frequent USCS types per USDA classification are highlighted in yellow unless there is a clearly dominant type, and then only one is highlighted.

3.2 Data from Waterways Experiment Station (1961)

As part of several trafficability studies, WES collected data from nearly 200 sites in 44 states, mainly east of the Mississippi River, from 1951 to 1958. USDA designation was done using a hydrometer while USCS classification was determined from the Atterberg limits and sieve analysis. The results presented in Table 9 summarize information found in Tables B1–B5 located in the back of the WES report. The WES authors noted that better classification can be determined if grain size distribution is known above and beyond the textural designation.

3.3 Data from Wilson, Nuttall, Raimond Engineers (1965)

This report is a collection of soil data sheets dating from 1945 through 1962. Grain size distribution and USCS and USDA classification are presented for each location. Locations range from Korea and the Philippians to the southeastern U.S. and a few sites in California and Arizona. Table 10 presents a compilation of these data sheets.

3.4 Data from Rollings and Rollings (1996)

To determine certain properties of soil that affects trafficability (the ability of a soil to permit the movement of a vehicle), Turnbull and Knight (1961) summarized the results of in-situ tests performed at several hundred sites. The analyzed soil layer was from 6 to 12 in (0.15–0.30 m) below the surface. Normally, this top layer of soil is not considered in soil mechanics

problems; but for engineers interested in soil trafficability, properties of this layer are very important.

The tests were performed over a number of years and represent a wide range of soil types in humid-climate areas of the United States. The tests determined moisture content, density, and strength. Soils were very wet, but not frozen; and data from clean sands and gravels were not collected. All 1176 soil samples collected and analyzed were classified in both USCS and the USDA system.

Rollings and Rollings (1996) summarize the data of Turnbull and Knight (1961) along with data from WES (1963) to calculate the percentage of each USDA soil type in the various USCS categories. For example, 50% of the USDA sands mapped to USCS type SM, 47% to SP-SM and 3% to SM-SC. Table 11 presents their results. The two most frequent USCS classifications for each USDA type are denoted in yellow.

3.5 Data from Curtis (2005)

The Curtis (2005) study was interested in the electromagnetic properties of soil. Most of the data was collected from 1990 to 2001, mainly from military installations in the U.S., Europe, and the Middle East. Some of the samples were “prepared” by WES researchers while others were obtained from the National Soils Survey Center in Lincoln, NE (Curtis 2005). Of the 1080 samples in his study, between 300 and 400 are classified in both USCS and the USDA system. Curtis (2005) mapped the USCS classed soils onto the USDA triangle, which is presented in Figure 4 below. Unfortunately, the data used to create this figure is unavailable. Therefore, we physically counted the individual points to come up with the mapping found in Table 12.

Figure 4. USCS classifications mapped onto the USDA triangle (Curtis 2005).

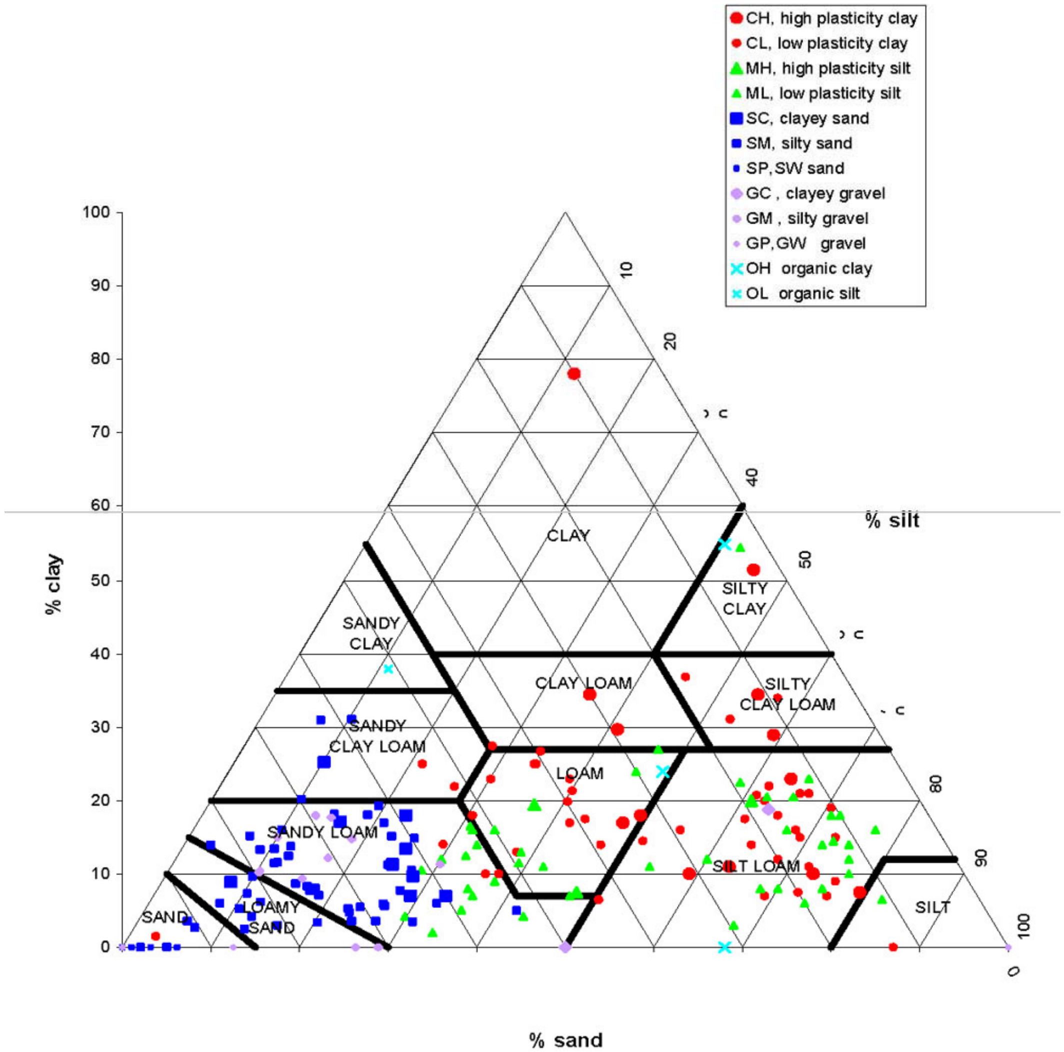


Table 8. SSURGO, USDA, and USCS soil mapping. The most frequent USCS classifications for each USDA type are denoted in yellow.

	USCS Classification																									
USDA Classification	GW	GP	GM	GC	SW	SP	SM	SC	ML	CL	OL	CH	MH	OH	Pt	GW-GM	GW-GC	GP-GM	GP-GC	GC-GM	SW-SM	SP-SM	SP-SC	SM-SC	CL-ML	Total
Sand	1	3	5	3	0	7	73	16	23	67	0	7	2	0	5	2	0	10	0	5	0	29	1	9	12	280
Loamy Sand	0	1	10	7	0	1	102	10	21	73	0	11	2	0	3	3	0	3	0	1	3	16	0	29	19	315
Sandy Loam	6	3	70	48	1	3	264	75	132	194	49	39	3	0	4	7	2	17	0	50	1	11	1	154	87	1221
Sandy Clay Loam	0	0	11	15	0	0	22	48	18	78	0	10	1	0	0	1	1	1	1	9	1	6	0	26	19	268
Sandy Clay	0	0	0	1	0	0	0	2	0	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	7
Loam	2	7	100	133	1	6	134	74	182	624	2	71	17	0	10	0	3	20	6	68	0	27	3	57	106	1653
Silt Loam	0	3	59	171	0	2	87	44	402	906	3	124	17	0	5	3	2	8	2	53	2	15	5	37	222	2172
Silt	0	0	0	0	0	0	1	0	8	1	0	1	0	0	0	0	0	0	0	0	0	0	0	1	0	12
Clay Loam	6	1	43	83	0	1	53	34	77	441	0	65	4	0	9	3	0	5	0	13	1	5	0	25	41	910
Silty Clay Loam	0	1	21	107	1	2	58	29	150	836	1	130	13	0	0	0	0	3	0	21	2	10	0	22	58	1465
Clay	2	0	24	90	0	2	35	28	41	194	0	160	5	0	2	1	1	5	1	17	0	1	0	15	24	648
Silty Clay	1	0	4	19	1	0	13	6	28	128	0	75	5	0	3	1	0	0	1	3	0	0	0	4	12	304
"Peat"	0	0	0	0	0	0	1	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	3
TOTAL	18	19	347	677	4	24	843	366	1082	3545	55	693	69	0	43	21	9	72	11	240	10	120	10	379	601	9258

Table 9. Waterways Experiment Station (1961) data. The most frequent USCS classifications for each USDA type are denoted in yellow.

USDA Classification	USCS Classification																		Total
	GW	GP	GM	GC	SW	SP	SM	SC	ML	CL	OL	CH	MH	OH	Pt	SP-SM	SM-SC	CL-ML	
Sand	0	0	0	0	0	0	24	0	0	0	0	0	0	0	0	20	1	0	45
Loamy Sand	0	0	0	0	0	0	56	1	0	0	0	0	0	0	0	0	0	0	57
Sandy Loam	0	0	0	0	0	0	86	27	44	18	5	1	0	4	0	0	19	10	215
Sandy Clay Loam	0	0	0	0	0	0	3	6	2	19	0	0	0	0	0	0	0	0	31
Sandy Clay	0	0	0	0	0	0	0	1	0	1	0	0	0	0	0	0	0	0	2
Loam	0	0	1	1	0	0	0	0	38	89	6	5	1	9	0	0	0	19	169
Silt Loam	0	0	0	0	0	0	0	0	172	216	9	11	16	10	0	0	0	48	482
Silt	0	0	0	0	0	0	0	0	10	0	0	0	0	0	0	0	0	0	10
Clay Loam	0	0	0	0	0	0	0	0	2	31	0	5	1	1	0	0	0	0	40
Silty Clay Loam	0	0	0	0	0	0	0	0	1	51	0	22	1	2	0	0	0	1	78
Clay	0	0	0	0	0	0	0	0	1	5	0	25	4	3	0	0	0	0	38
Silty Clay	0	0	0	0	0	0	0	0	0	5	0	18	0	0	0	0	0	0	23
“Peat”	0	0	0	0	0	0	0	0	0	0	0	0	0	0	6	0	0	0	6
TOTAL	**0**	**0**	**1**	**1**	**0**	**0**	**169**	**35**	**270**	**435**	**20**	**87**	**23**	**29**	**6**	**20**	**21**	**78**	**1196**

Table 10. Wilson, Nuttall, Raimond Engineers (1965) data. The most frequent USCS classifications for each USDA type are denoted in yellow.

USDA Classification	USCS Classification																			Total
	GW	GP	GM	GC	SW	SP	SM	SC	ML	CL	OL	CH	MH	OH	Pt	SP-SW	SP-SM	SM-SC	CL-ML	
Sand	0	2	0	0	1	12	0	0	0	0	0	0	0	0	0	12	0	0	0	**27**
Loamy Sand	0	0	0	0	0	1	5	0	0	0	0	0	0	0	7	0	0	0	0	**13**
Sandy Loam	0	0	0	0	0	0	8	2	8	2	0	0	0	0	12	0	1	1	2	**36**
Sandy Clay Loam	0	0	0	0	0	0	0	5	0	6	0	0	0	0	0	0	0	0	0	**11**
Sandy Clay	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	1	**2**
Loam	0	0	0	0	0	0	0	0	10	14	0	0	0	0	0	0	0	0	2	**26**
Silt Loam	0	0	0	0	0	0	0	0	23	17	0	4	1	0	0	0	0	0	0	**45**
Silt	0	0	0	0	0	0	0	0	5	1	0	0	1	0	0	0	0	0	0	**7**
Clay Loam	0	0	0	0	0	0	0	0	0	3	0	1	0	0	0	0	0	0	0	**4**
Silty Clay Loam	0	0	0	0	0	0	0	0	2	3	0	4	0	0	0	0	0	0	0	**9**
Clay	0	0	0	0	0	0	0	0	0	1	0	4	0	0	0	0	0	0	0	**5**
Silty Clay	0	0	0	0	0	0	0	0	0	0	0	9	4	0	0	0	0	0	0	**13**
"Peat"	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**0**
TOTAL	**0**	**2**	**0**	**0**	**1**	**13**	**13**	**7**	**48**	**47**	**0**	**23**	**6**	**0**	**19**	**12**	**1**	**1**	**5**	**198**

Table 11. Rollings and Rollings (1996) data. The most frequent USCS classifications for each USDA type are denoted in yellow.

USDA Classification	USCS Classification																		Total
	GW	GP	GM	GC	SW	SP	SM	SC	ML	CL	OL	CH	MH	OH	Pt	SP-SM	SM-SC	CL-ML	
Sand	0	0	0	0	0	0	50	0	0	0	0	0	0	0	0	47	3	0	**100**
Loamy Sand	0	0	0	0	0	0	98	2	0	0	0	0	0	0	0	0	0	0	**100**
Sandy Loam	0	0	1	0	0	0	41	14	19	9	2	0	0	2	0	0	8	4	**100**
Sandy Clay Loam	0	0	0	0	0	0	11	25	7	54	0	0	0	0	0	0	3	0	**100**
Sandy Clay	0	0	0	0	0	0	0	50	0	50	0	0	0	0	0	0	0	0	**100**
Loam	0	0	1	1	0	0	0	0	22	52	3	3	1	6	0	0	0	11	**100**
Silt Loam	0	0	0	0	0	0	0	0	36	45	2	2	3	2	0	0	0	10	**100**
Silt	0	0	0	0	0	0	0	0	91	9	0	0	0	0	0	0	0	0	**100**
Clay Loam	0	0	0	0	0	0	0	0	5	75	0	15	3	2	0	0	0	0	**100**
Silty Clay Loam	0	0	0	0	0	0	0	0	1	67	0	27	1	3	0	0	0	1	**100**
Clay	0	0	0	0	0	0	0	0	5	24	0	71	0	0	0	0	0	0	**100**
Silty Clay	0	0	0	0	0	0	0	0	3	13	0	66	10	8	0	0	0	0	**100**
"Peat"	0	0	0	0	0	0	0	0	0	0	0	0	0	0	100	0	0	0	**100**
TOTAL	**0**	**0**	**1**	**1**	**0**	**0**	**200**	**91**	**189**	**398**	**7**	**184**	**18**	**23**	**100**	**47**	**14**	**25**	**1300**

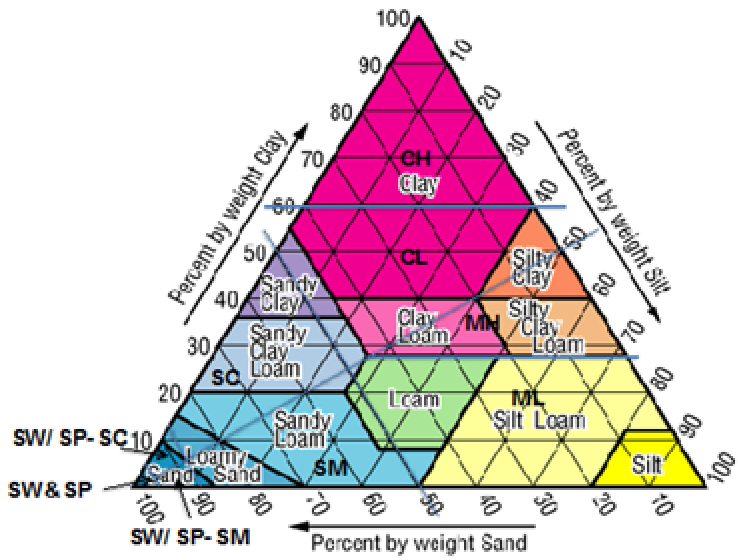
Table 12. Curtis (2005) data. The most frequent USCS classifications for each USDA type are denoted in yellow.

USDA Classification	USCS Classification																	Total
	GW	GP	GM	GC	SW	SP	SM	SC	ML	CL	OL	CH	MH	OH	Pt	SP-SW	GP-GW	
Sand	0	0	0	0	0	0	4	0	0	1	0	0	0	0	0	3	2	10
Loamy Sand	0	0	2	0	0	0	9	0	0	0	0	0	0	0	0	0	0	11
Sandy Loam	0	0	8	1	0	0	30	8	13	3	0	0	0	0	0	0	0	63
Sandy Clay Loam	0	0	0	0	0	0	3	1	0	2	0	0	0	0	0	0	0	6
Sandy Clay	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	1
Loam	0	0	1	0	0	0	0	0	8	11	1	2	2	0	0	0	0	24
Silt Loam	0	0	0	1	0	0	0	0	20	21	1	5	1	0	0	0	0	49
Silt	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	1	3
Clay Loam	0	0	0	0	0	0	0	0	0	2	0	2	0	0	0	0	0	4
Silty Clay Loam	0	0	0	0	0	0	0	0	0	3	0	2	0	0	0	0	0	5
Clay	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	1
Silty Clay	0	0	0	0	0	0	0	0	1	0	1	1	0	0	0	0	0	3
“Peat”	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
TOTAL	0	0	10	2	0	0	46	9	43	44	3	13	3	1	0	3	3	180

3.6 Data from Ayers et al. (2011)

Ayers et al. (2011) present a USCS version of the USDA triangle. We overlaid this onto the USDA one as shown in Figure 5. We use this triangle as a mapping scheme between the USDA and USCS schema.

Figure 5. USCS classifications (Ayers et al. 2011) mapped onto the USDA triangle.



Using an area-weighted mean, we estimated the top two USCS classifications for each USDA type. In some cases, such as with clay, there is only one mapping. If two USCS classifications have approximately equal area means under the same USDA classification, both USCS classifications are considered as the most probable value. For example, clay loam can be classified as either MH or CL with equal probability by area mean. Table 13 shows our results.

Table 13. USCS classification best fit for USDA classification based on Ayers et al. (2011).

USDA Classification	USCS Classification	
	Most Probable	Possible
Sand	SW, SP	—
Loamy Sand	SM	SC
Sandy Loam	SM	—
Sandy Clay Loam	SC	—
Sandy Clay	SC	CL
Loam	ML	—
Silt Loam	ML	—
Silt	ML	—
Clay Loam	CL, MH	—
Silty Clay Loam	MH	—
Clay	CH	CL
Silty Clay	CL, MH	—
Peat	—	—

3.7 Data from Baylot et al. (2013)

Baylot et al. (2013) conducted an analysis to provide ground vehicle cross-country mobility predictions for the Combatant Commands using the NATO (North Atlantic Treaty Organization) Reference Mobility Model (NRMM). Soil data from the Air Force Weather Agency (AFWA), which uses FAO data, was used to calculate soil moisture. FAO classifies their data using the USDA system. To calculate soil strength, NRMM needs USCS soil classifications. Table 74 from the Baylot et al. (2013) report contains their mapping algorithm for converting from USDA to USCS classifications. Table 14 is a copy of their conversion scheme.

Table 14. Soil type conversion (Baylot et al. 2013).

FAO Number	USDA Classification	USCS Classification	STP Number
1	Sand	SP, poorly sorted sand	6
2	Loamy Sand	SM, silty sand	7
3	Sandy Loam	SC, clayey sand	8
4	Silty Loam	SM, silty sand	7
5	Silt	ML, low plasticity silt	9
6	Loam	CL, low plasticity clay	10
7	Sandy Clay Loam	SC, clayey sand	8
8	Silty Clay Loam	CL, low plasticity clay	10
9	Clay Loam	CL, low plasticity clay	10
10	Sandy Clay	SC, clayey sand	8
11	Silty Clay	CL, low plasticity clay	10
12	Clay	CH, high plasticity clay	12
13	Organic	OH, high plasticity organic soil	14
14	Water	---	−999
15	Bedrock	GM, silty gravel	3
16	Other	---	−999

3.8 Mapping scheme from the FASST (Fast All-season Soil STrength) model (Frankenstein and Koenig 2004)

As stated on the U.S. Army Engineer Research and Development Center website (Frankenstein 2014),

> The one-dimensional dynamic state-of-the-ground model FASST (Fast All-season Soil Strength) was developed by researchers at the Engineer Research and Development Center's Cold Regions Research and Engineering Laboratory (EDRC-CRREL). . . . FASST calculates the ground's moisture and/or ice content, temperature, and freeze/thaw profiles, as well as soil strength and surface ice and snow accumulation/depletion. FASST's fundamental operations are the calculation of an energy and water budget that quantifies both the flow of heat and moisture within the soil and also the exchange of heat and moisture at all interfaces (ground/air or ground/snow; snow/air) using both meteorological and terrain data.

FASST (Frankenstein and Koenig 2004) can use the USDA classification system but was originally written to handle the USCS method. Because there is not a direct relationship between both classification systems, substantial overlap can occur. As stated before, a large amount of soils data has only USDA classification; and currently, FASST uses its own conversion scheme to move from one system to another as shown in Table 15.

Table 15. USDA classification equivalency in USCS classification (Frankenstein 2014).

USDA Classification	USCS Classification
Sand	SP
Loamy Sand	SM
Sandy Loam	SM
Sandy Clay Loam	SC
Sandy Clay	SC
Loam	ML
Silt Loam	ML
Silt	ML
Clay Loam	CL
Silty Clay Loam	CL
Clay	CH
Silty Clay	CH
Peat	Pt
Bedrock	Ro

4 Analysis

Tables 16 and 17 summarize our findings. In Table 16, for each USDA category, we simply list the highest and second highest frequency of USCS soil types found in Tables 8–15. For USDA categories that had several USCS types with nearly identical frequencies, we listed them all. In Table 17, we combined all data from Tables 8–12 then determined the frequency distribution of USDA to USCS soil types. We also used the mapping scheme included in both the FASST model and Baylot et al. (2013) as part of our analysis. Finally, overlapping the Ayers et al. (2011) USCS triangle with the USDA one, we chose the two best area-weighted USCS classifications for each USDA one.

In Tables 16 and 17, "MP" stands for the "most probable" USCS classification and "P" for the next "possible" USCS classification. The last column of Table 17 has the USCS classification consensus for each USDA classification.

Table 16. Most probable (MP) and possible (P) USCS classifications per USDA texture classification.

USDA Classification	USCS Classification													
	SSURGO (2014) Table 8		WES (1961) Table 9		Wilson et al. (1965) *Table 10*		Rollings and Rollings (1996) *Table 11*		Curtis (2005) *Table 12*		Ayers et al. (2011) *Table 13*		Baylot et al. (2013) *Table 14*	FASST (2004) *Table 15*
	MP	P	MP	P	MP	P	MP	P	MP	P	MP	P	MP	MP
Sand	SM, CL	–	SM, SP-SM	–	SP, SP-SW	–	SM, SP-SM	—	SM, SP-SW, GP-GW	—	SW, SP	—	SP	SP
Loamy Sand	SM	CL	SM	–	Pt	SM	SM		SM	GM	SM	SC	SM	SM
Sandy Loam	SM	CL	SM	–	Pt	SM, ML	SM	SC, ML	SM	ML	SM	—	SC	SM
Sandy Clay Loam	SM	CL	CL	–	CL, SC	–	CL	ML	SM, SC, CL	–	SC	—	SC	SC
Sandy Clay	CL, SC	CL-ML	SC, CL	–	CL, CL-ML	–	SC, CL	–	OH	–	SC	CL	SC	SC
Loam	CL	–	CL	ML	CL, ML	–	CL	ML	CL, ML	–	ML	—	CL	ML
Silt Loam	CL	–	CL	ML	ML	CL	CL, ML	–	ML, CL	–	ML	—	SM	ML
Silt	ML	–	ML	–	ML	CL, MH	ML	–	ML, CL, GP-GW	–	ML	—	ML	ML
Clay Loam	CL	–	CL	–	CL, CH	–	CL	–	ML, OL, CH	–	CL, MH	—	CL	CL
Silty Clay Loam	CL	–	CL	CH	CH, CL, ML	–	CL	CH	–	–	MH	—	CL	CL
Clay	CL, CH	–	CH	–	CH, CL	–	CH	CL	–	–	CH	CL	CH	CH
Silty Clay	CL	CH	CH	–	CH	OH	CH	–	–	–	CL, MH	—	CL	CH

Table 17. Consensus of the most probable (MP) and possible (P) USCS classification per USDA texture classification.

USDA Classification	USCS classification: SSURGO (2014) *Table 8*, WES (1961) *Table 9*, Wilson et al. (1965) *Table 10*, Rollings and Rollings (1996) *Table 11*, Curtis (2005) *Table 12*		Ayers et al. (2011) *Table 13*		Baylot et al. (2013) *Table 14*	FASST (2004) *Table 15*	Consensus
	MP	P	MP	P	MP	MP	
Sand	SM	SP-SM	SW, SP	—	SP	SP	SP
Loamy Sand	SM	CL	SM	SC	SM	SM	SM
Sandy Loam	SM	ML, CL	SM	—	SC	SM	SM
Sandy Clay Loam	CL	SC	SC	—	SC	SC	SC
Sandy Clay	SC, CL	—	SC	CL	SC	SC	SC,
Loam	CL	ML	ML	—	CL	ML	CL
Silt Loam	CL	ML	ML	—	SM	ML	ML
Silt	ML	—	ML	—	ML	ML	ML
Clay Loam	CL	—	CL, MH	—	CL	CL	CL
Silty Clay Loam	CL	ML, CH	MH	—	CL	CL	CL
Clay	CH, CL	GC	CH	CL	CH	CH	CH
Silty Clay	CH, CL	—	CL, MH	—	CL	CH	CH

5 Conclusion

We downloaded and organized data according to the USDA and USCS soil types from the SSURGO database. We then compared our results with four other USDA to USCS soil mapping schema and determined the most frequent USDA classifications occurring in USCS. We found good consensus between the data sources for most of the soil types. Based on our results we recommend the following:

1. **Sand** in USDA textural classification should be classified as **SP** in USCS.

2. **Loamy Sand** in USDA textural classification should be classified as **SM** in USCS.

3. **Sandy Loam** in USDA textural classification should be classified as **SM** in USCS.

4. **Sandy Clay Loam** in USDA textural classification should be classified as **SC** in USCS.

5. **Sandy Clay** in USDA textural classification should be classified as **SC** in USCS. No significant difference in occurrence exists between both USCS classifications.

6. **Loam** in USDA textural classification should be classified as **CL** in USCS.

7. **Silt Loam** in USDA textural classification should be classified as **ML** in USCS.

8. **Silt** in USDA textural classification should be classified as **ML** in USCS.

9. **Clay Loam** in USDA textural classification should be classified as **CL** in USCS.

10. **Silty Clay Loam** in USDA textural classification should be classified as **CL** in USCS.

11. **Clay** in USDA textural classification should be classified as **CH** in USCS. No significant difference in occurrence exists between both USCS classifications.

12. **Silty Clay** in USDA textural classification should be classified as **CH** in USCS. No significant difference in occurrence exists between both USCS classifications.

This information provides a guide to map from the USDA textural soil classification system to the USCS schema. Being able to predict which USCS soil classification corresponds to a USDA classification is a great advantage for particular purposes. If soil properties described in USCS classification are needed and only USDA classification is available, a preliminary USCS classification can be obtain from this analysis. This could save time and money as some tasks can be done before the actual USCS classification is determined. Regardless, we recommend being careful when using this as a mapping scheme. For high quality control, it is better to determine USCS classifications by laboratory analysis instead of following a mapping scheme based on probabilities.

However, this analysis provides a step for finding relationships between different soil classification systems, which can lead to future unification of soil databases and to the creation of a universally accepted classification system.

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14. ABSTRACT

The U.S. Department of Agriculture (USDA) soil classification system is relatively simple to apply while the Unified Soil Classification System (USCS) is more complex. As a result, the USDA system, or a similar method, is more commonly used. However, unless taking direct measurements, the USCS classification is needed to determine soil strength. There is no direct relationship between these soil classification systems, and moving from one scheme to another can be tedious and is inexact. Currently, individual researchers, engineers, and soil scientists have their own mapping to move from one system to another, which can lead to confusion when sharing work with others. A consensus method for mapping from one classification scheme to another would avoid this. By analyzing the mappings from six data sets containing thousands of samples, we form such a consensus.

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